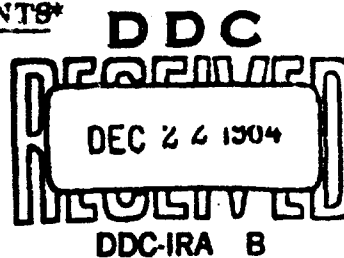


AD 609323

PILOT STATURE IN RELATION TO COCKPIT SIZE: A HIDDEN FACTOR INNAVY JET AIRCRAFT ACCIDENTS*

by

George I. Lodge, Ph.D.**

INTRODUCTION

"The A4D cockpit was designed around figures taken from Wright Air Development Center Technical Report 52-321, ANTHROPOMETRY OF FLYING PERSONNEL....As the A4D cockpit is designed to accommodate the measurements of the 5 to 95 percentile flying personnel, the dimensions given in the 95th percentile column are the maximum dimensions with which the pilot can safely fly the aircraft." (1)

Cockpit dimensions of all models of Naval aircraft currently in service have been influenced by the WADC Technical Report 52-321 (4). Other manufacturers, as well as Douglas, have had to depend upon the anthropometric standards published in that report because they constituted the most authoritative measurements applying to American airmen, that were available. However, in July 1960 the Air Crew Equipment Laboratory (ACEL) of the Naval Air Materiel Center issued a "Compilation of Anthropometric Measures on U. S. Navy Pilots," based upon a representative sampling of 1190 Navy pilots from operating squadrons (2,3). A conclusion in the ACEL Report was that significant differences existed so far as Navy pilots were concerned, with regard to some of the more important dimensions including overall height.

Continuing study of Medical Officer's Reports (MORs) of Naval Aircraft Accidents has increasingly reinforced the suspicion that pilot stature in relation to cockpit dimensions might be operating as a covertly contributing factor to a number of mishaps.

Figure 1 clearly demonstrates the striking differences in stature between the WADC standardization population and the Navy pilot population studied by the Air Crew Equipment Laboratory. Navy pilots average more than an inch taller than the members of the 'standard' population around whose measurements the cockpits were designed.

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The WADC 95th percentile (73.1 in.) represents, according to the Douglas Aircraft Company, the maximum "with which the pilot can safely fly the aircraft." This value is exceeded by about 12% of the Navy pilots who presumably, therefore, cannot safely fly the aircraft. Yet stature is but one of several critical bodily dimensions involved in cockpit design considerations. Others such as sitting height, leg length, functional reach, buttock circumference, etc., are beyond the scope of the present report. These latter measurements, however, all have significant positive correlations with stature (2). Therefore, if a pilot exceeds safe design limits in one dimension, it is extremely likely that he does so in a number of other dimensions as well. This consideration underscores the fact that any cut-off point such as "95th percentile" can differentiate a "safe" from an "unsafe" man-cockpit combination only in terms of probabilities. Thus the true situation must be defined in terms of a gradient through which the man-cockpit combination becomes increasingly inefficient the more it deviates from the optimum for any particular individual. The problem parallels the more personal one of determining one's best fit in a hat, shoes or jacket. Moreover, an overly-tight fit usually produces more sensory interference than one that is too loose.

Since cockpits have been built on the basis of the WADC standards, and since Navy pilots as a group considerably exceed these standards does it not follow that, so far as existing aircraft are concerned, the taller the pilot the greater his disadvantage? Conversely, will the pilot whose bodily dimensions correspond closely with the design specifications of the cockpits enjoy an advantage when it comes to adapting his posture and muscular responses to the aircraft's operating requirements?

It is expected that these considerations, if valid, will be reflected in our MORs if the latter are examined with respect to the statures of the pilots concerned. Moreover, (a) since high-performance jet aircraft demand more of a pilot's capacity for split-second response coordination, than do the slower propeller-driven models, and (b) since jet cockpits often are smaller than is the case with most propeller aircraft, it is further expected that tall pilots will be at a greater disadvantage in jets than in propeller models.

The hypotheses which we shall proceed to test, then, are the following:

(1) Tall Navy pilots will show a greater tendency than short ones to pilot-induced accidents.

(2) This tendency will be more pronounced with jet than with propeller driven aircraft.

Subjects of the present report

The data on which the present report is based concern all Navy and Marine pilots in control of fixed wing aircraft having mishaps between 1 July 1958 and 1 November 1961, in which a pilot factor was officially designated as a contributing cause. Jet accident pilots comprise one group (N=680), while pilots involved in mishaps with propeller-driven aircraft comprise a second group (N=424). For present purposes we shall consider all of these mishaps as accidents even though each group includes a few (less than 5%) "flight hazards", "incidents" and "forced landings" which, by definition are somewhat

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LODGE, George T. (U. S. Naval Aviation Safety Center)

Pilot stature in relation to cockpit size: a hidden factor in Navy jet aircraft accidents. (Abstract of paper presented at 71st Annual Convention of the American Psychological Association, Philadelphia, Pa., 4 September 1963.)

A recent anthropometric survey of U. S. Navy pilots showed their average height to be significantly taller than that of the non-Navy population who provided the measurement standards around which most contemporary aircraft cockpit dimensions are based. Taller individuals among Navy pilots, therefore, probably would have more difficulty than shorter ones in operating the aircraft, and one would expect this handicap to be reflected in their respective susceptibility to mishaps. Analysis of 680 jet accidents disclosed that pilots exceeding 72" were disproportionately represented ($P < .01$) in "pilot-factor" accidents. Implications for pilot selection and assignment are discussed.

less serious than 'accidents.'

Analysis of the data

Figure 1 shows the height distributions for both the jet- and prop-accident groups. The curve for the latter lies, more or less, between that of the former and of the ACEL norm group. However, the prop-accident pilots coincide more closely with the norm group throughout most of the right-hand side of the curve, than do the jet-accident pilots.

Tables 1 and 2 provide the information necessary for appraising the significance of the differences shown. The results imply most strongly that future experience will confirm the finding that jet-accident pilots tend to be taller as a group than other pilots. The prop-accident group is shorter than the jet-accident group and taller than the norm group as predicted, although the differences here are non-substantial.

If we divide the range of stature into three parts corresponding to "short," "medium" and "tall" individuals, further analysis becomes simplified. Choice of cutting points is necessarily an arbitrary matter, but, when within reasonable limits, does not appreciably influence the overall results. Therefore, intervals have been selected as shown in Table 3, so as approximately to place the middle half of all the accident pilots within the span between 69.0 and 72.0 inches.

A chi square test based on the material in Table 3 compels rejection of the null hypothesis that "jet-accident pilots do not differ from the norm with respect to stature" ($P < .01$). A corresponding test of the prop-accident group in relation to the norm does not yield appreciable differences. The proportion of jet-accident pilots exceeding 72 inches, and the proportion under 69 inches, differ respectively from their norm group counterparts in the predicted directions with statistical significance as indicated by asterisks. While the ratios set forth in Table 3 are, by their nature, less stable than the other values shown, the results point unmistakably to a conclusion that a tall jet pilot has highly unfavorable gambling odds by comparison with those of short or medium stature.

The material thus far presented has been obtained by combining data relating to all types of jet or propeller-driven aircraft. To what extent do these generalizations hold if applied to pilots of particular models? While some differences, obviously, are to be expected between models, Figure 2 indicates that a good deal of similarity and consistency prevails in the patterning, even though the numbers involved in each individual instance are relatively small. Figure 2 shows the models most heavily represented, from the standpoint of gross numbers, in the present group. (Twenty six other models, not shown here, had one or more mishaps entering into the overall calculations, but there were too few of each to justify inclusion here.) For each model named in Figure 2 is also shown the proportion, in each of the three stature categories, of pilots causing or contributing to the mishaps under study. The dotted horizontal lines indicate the proportion taller than 72.0 inches or shorter than 69.0 inches, to be expected on the basis of the ACEL survey. It will be observed that seven of the eight jet models represented in the figure support the hypothesis that tall pilots are more prone than short ones to pilot induced accidents; the F-3 (F3H) constituting the single exception. It is to be

inferred, therefore, that the dimensions of the latter's cockpit are more compatible with those of the Navy pilot population than is the case with the other jet models listed. The corollary hypothesis, that short pilots enjoy an advantage in the operation of these aircraft is supported in the records of all seven of the single-seat jets. In the case of the F-6 (F4D) this advantage is especially impressive. In contrast, however, it must be noted that short pilots appear at a relative disadvantage in the A-1 (A-1D).

Discussion

It is not a contention of this report that a pilot's stature in itself produces accidents. The real point at issue is the fact that the cockpit dimensions of existing Navy aircraft simply do not match the bodily dimensions of a large proportion of the Navy pilot population. If the ACEL height distribution is representative of the Navy's jet pilots, the conclusion is unavoidable that tall pilots have an accident rate significantly worse than that to be expected if height were not a contributory factor. Correspondingly, short pilots have a significantly more favorable rate. If the ACEL data are not representative of the jet pilots, there can only be two other possibilities.

(a) The ACEL results understate the proportion of tall pilots. In this case our figures do them an injustice. On the other hand, this would mean that existing cockpits, based on WADC standards, are even more inappropriate for the majority of Navy pilots than has been indicated in Figure 1.

(b) The ACEL results overstate the proportion of tall pilots. If this should be the case, then the present findings are underestimations, and the situation is even more serious than the present figures show.

Appreciable savings in terms of combat readiness, lives and equipment hinge upon recognition of the importance of anthropometric components in weapons systems. For instance, during the 40 months covered by this report, jet pilots exceeding 72 inches accumulated 37 accidents (or 5-1/2 percent) more than normal expectancy. On the annual basis, these figures would represent more than 11 accidents having a total cost over \$7 million and involving two or more fatalities.

Since accident rates are, in effect, an index of the operating efficiency of a man-machine system, it appears probable that tall pilots are handicapped in a number of less spectacular ways by the cockpits of many contemporary aircraft. It should be of interest, for example, to examine the influence of stature upon performance in various activities demanding precise sensori-motor coordinations: aerobatics, gunnery, bombing, inflight refueling, etc., for various types of cockpits. Further, it would not be surprising to discover that such problems as fatigue and vertigo are aggravated by the postural stresses imposed by workspaces that are too cramped.

The foregoing observations sharply point up several practical steps that must be taken to reduce the number of accidents associated with dimensional incompatibility between man and cockpit:

(1) Cockpits must be constructed to accommodate the dimensions of the individuals who are to occupy them. Many of the accidents here classed as "pilot-factor" might, just as accurately, have been attributed to "design factor."

(2) Initial selection of pilots must take account of the relationship between stature and the efficient operation of existing aircraft and those contemplated for the future.

(3) A pilot's physical measurements must be considered in determining his duty assignment. Some aircraft, more than others, penalize height deviations -- whether too tall or too short. (See Figure 2.)

The question may well be raised as to why, if the facts are really as patent as here set forth, that the problem was not recognized long ago and steps taken for its correction. The answer doubtless lies in the fact that it is extremely difficult to distinguish the significance of variables of this nature in studying any individual accident. One cannot see the woods because of the trees. Only after a synoptic view has been achieved, as from the Naval Aviation Safety Center's records, are such factors readily identified -- obvious though they may appear in retrospect.

Summary and Conclusion

An earlier study (ACEL) has shown that Navy pilots are taller throughout the percentile range than the WAIC's "flying personnel" whose anthropometric measurements constituted the standards upon which contemporary aircraft cockpit dimensions have been based. The Navy's taller pilots, therefore, would be expected to find more difficulty than the shorter ones, in making appropriate responses while operating the aircraft. It seemed likely that this situation would be reflected in the 'pilot factor' accident frequencies. Two hypotheses were formulated (a) Tall pilots will show a greater tendency to pilot-induced accidents than short ones, and (b) this will be more pronounced with jet than with propeller-driven aircraft. Records of 680 jet and 424 propeller aircraft accidents, all involving a pilot factor, were reviewed. Hypothesis (a) was amply confirmed ($P < .01$) in the case of jet pilots, of whom those exceeding 72 inches accounted for significantly more than their expected share of accidents. Prop-accident pilots showed a tendency in the predicted direction but with results falling short of statistical significance. Thus hypothesis (b) is also supported, although less conclusively. Some implications of these findings are mentioned with reference to cockpit design, operational efficiency, the selection and assignment of pilots, and the problem of accident reduction.

References

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(3) Jones, Walton L. & Gifford, Edmund C. Anthropometry of U. S. Navy Pilots, Aerospace Medicine 1962 (Nov), 33, 1298-1303.

(4) Hertzberg, H. T. E., Daniels, G. S. & Churchill, E. Anthropometry of flying personnel-1950. WADC Tech. Report 52-321, 1954 (Sep).

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Acknowledgement is made to Mrs. Evelyn Willoughby, Statistical Assistant, for her part in assembling and organizing this material.

TABLE 1

Means, standard deviations and standard errors of the means (in inches) of the height distributions of WADC and ACEL norm groups and of two groups of Navy accident pilots.

| | N | \bar{X} | S. D. | $s_{\bar{X}}$ |
|-----------------------------|------|-----------|-------|---------------|
| Air Force Norm Group (WADC) | 4062 | 69.11 | 2.44 | .04 |
| Navy Norm Group (ACEL) | 1190 | 70.29 | 2.28 | .07 |
| Prop. Acct. Group | 424 | 70.39 | 2.29 | .11 |
| Jet Acct. Group | 680 | 70.59 | 2.23 | .09 |

TABLE 2

Differences between mean statures, standard errors of the differences, critical ratios, and probabilities of true differences between the ACEL Navy norm group and the two groups of accident pilots.

| | Diff. | Sigma Diff. | C. R. | P |
|------------------------------------|-------|----------------|-------|-----------------|
| Navy Norm Group - Jet Acct. Group | .30 | .11 | 2.67 | <.01 |
| Navy Norm Group - Prop Acct. Group | .10 | .13 | 0.76 | Not significant |
| Jet Acct. Group - Prop Acct. Group | .20 | .17 | 1.20 | Not significant |

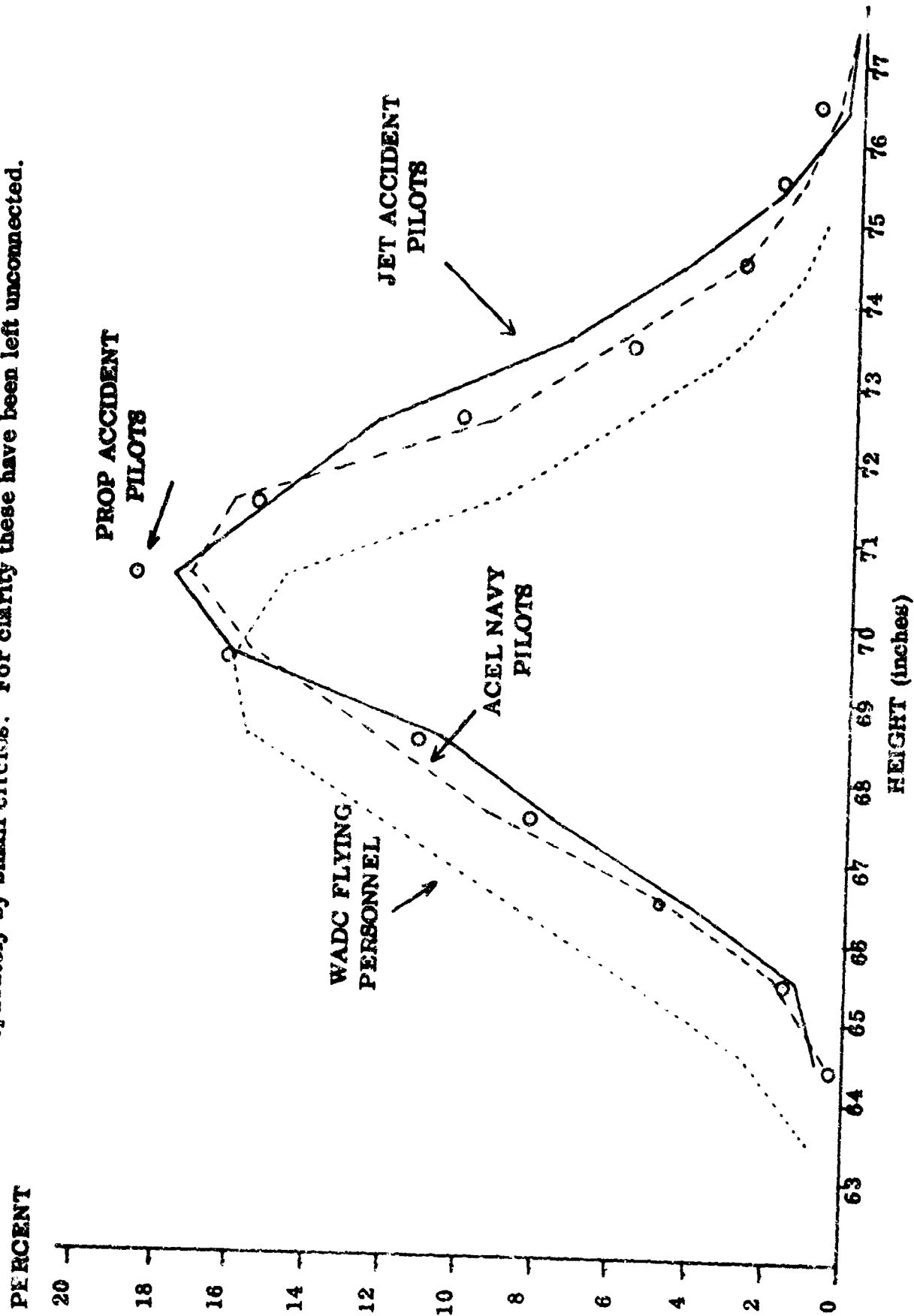
TABLE 3

Frequencies with which three groups of Naval Aviators fall into three height categories; ratios of the propeller and jet accident group frequencies to the frequencies to be expected on the basis of the ACEL norm group distribution.

| STATURE (Inches) | NORM GROUP | | PROP ACDT GROUP | | JET ACDT GROUP | | RATIO OF ACTUAL TO EXPECTED ACCIDENT FREQUENCIES | |
|---------------------|------------|------|--------------------|------|-------------------|-------|---|-----------|
| | N | % | N | % | N | % | PROP. GROUP | JET GROUP |
| >72.0 | 255.5 | 21.5 | 95.0 | 22.4 | 183.5 | 27.0* | 1.04 | 1.26 |
| 69.0 < 72.0 | 587.0 | 49.3 | 215.5 | 50.7 | 334.0 | 49.1 | 1.03 | 1.00 |
| <69.0 | 347.5 | 29.2 | 113.5 | 26.8 | 162.5 | 23.9* | .91 | .82 |
| TOTALS | 1190 | 100 | 424 | 100 | 680 | 100 | | |

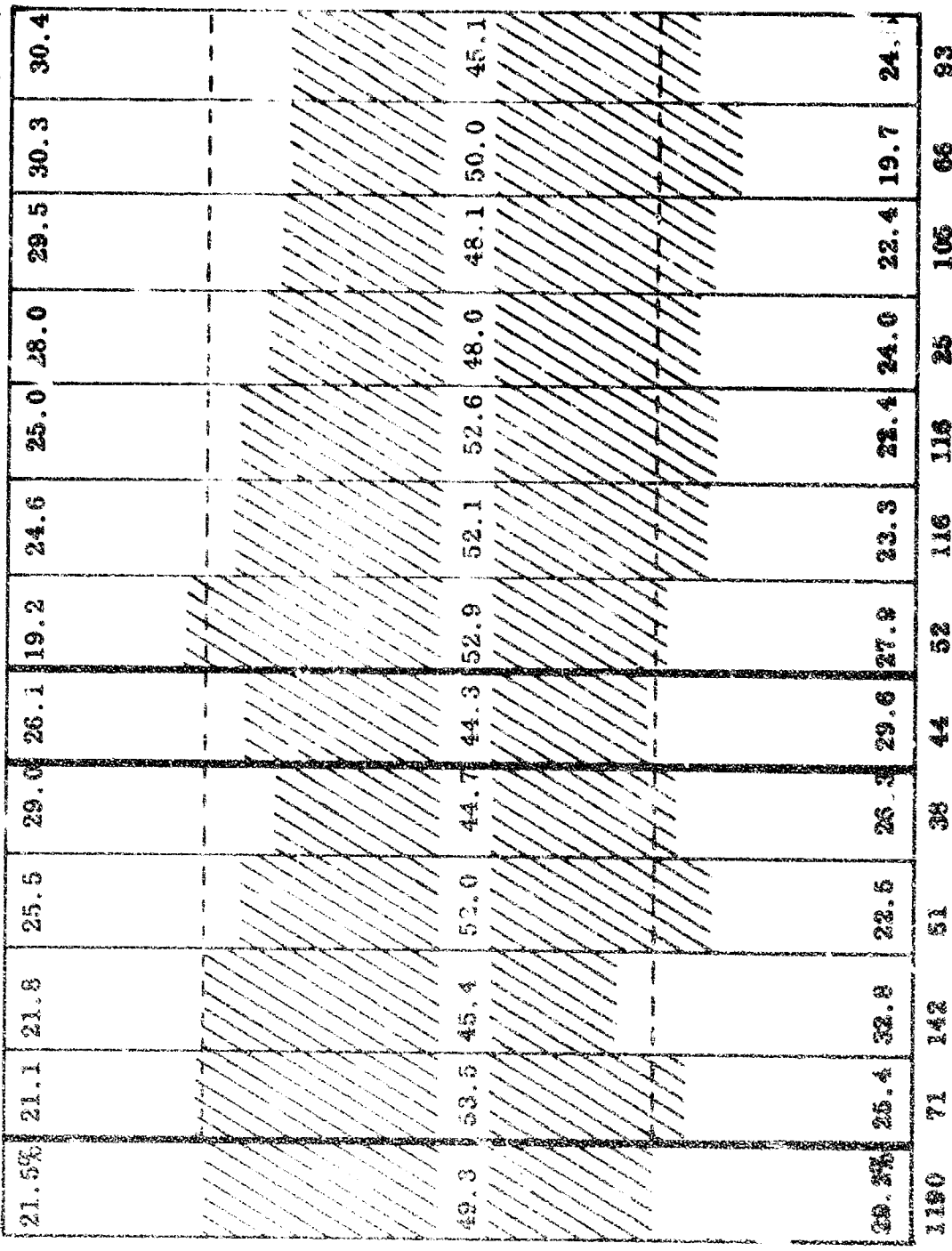
*P<.01

FIGURE 1: Stature Distribution of Navy Accident Pilots Compared with Normative Population Samples:
 (1) WADC flying personnel and (2) ACEL Navy pilots. Numerical properties of these curves are given in Table 1. The distribution of accident pilots in propeller-driven aircraft has been indicated separately by small circles. For clarity these have been left unconnected.



NAVY

NORM T-28 A-1 S-2 TC-45J A-3 F-3 P-8 A-4 F-11 F-1 F-6 F-9
GROUP (T-28) (AD) (S2E) (SNB) (A3D) (F3E) (F8U) (A4D) (F11F) (FJ) (F4D) (F9E)



72.0 INCHES OR MORE

SHADED AREA SHOWS
PERCENT BETWEEN
69.0 - 72.0 INCHES

LESS THAN 69.0 INCHES

FIGURE 2: Percent of Accident Pilots in Each of Three Stature Categories According to Model Aircraft